

Human  $\beta$ TrCP protein

5 The present invention relates to a novel human protein which is involved in the targeting of proteins towards proteasome degradation pathways. This protein, called h- $\beta$ TrCP, is capable of interacting notably with the Vpu protein of HIV-1 virus and with the cell proteins I $\kappa$ B,  $\beta$ -catenin and Skp1p.

10 The degradation of proteins by proteasome, a multiprotein complex present in all cells, is involved in numerous essential cell phenomena such as the control of cell proliferation, the renewal of proteins and the removal of incorrectly folded proteins, particularly in the endoplasmic reticulum (CIECHANOVER A., Cell, 79, 13-21, 1994). Numerous viruses, like HIV-1 virus, which degrades CD4 via one of its proteins Vpu (TRONO D., Cell, 82, 189-1992, 1995), exploit these cell pathways of protein degradation, in which the proteins are targeted towards proteasome by various interactions with other proteins before being degraded. To  
15 be targeted towards and degraded by proteasome, the proteins must generally be ubiquitinated beforehand by ubiquitin-ligase complexes. Furthermore, to be ubiquitinated, the proteins must often undergo modifications such as phosphorylations (CIECHANOVER A., Embo. J., 17, 7151-7160, 1998).

Several other proteins of the  $\beta$ TrCP type are known at the present time:

- 20 - the  $\beta$ TrCP protein of Xenope, described by Spevak et al. (Mol. Cell. Biol., 13, 4953-4966, 1993);
- the Slimb protein of drosophila, described by Jiang et al. (Nature, vol. 391, 29 January 1998); and
- 25 - the KIAA 0696 protein identified by Ishikawa et al. (DNA Research, 5, 169-176, 1998) during a systematic analysis of sequences expressed in the brain.

Jiang et al. showed that the Slimb protein of drosophila is involved in the stability of the Armadillo protein and the signaling of two metabolic pathways essential for development, namely the Hedgehog and Wingless pathways. They also showed that the Slimb protein has a homology of about 80% with the  $\beta$ TrCP  
30 protein of Xenope, none of whose functions was described by Spevak et al. As the  $\beta$ -catenin of Xenope or man, which is the homolog of the Armadillo protein of drosophila, seems to be targeted towards proteasome degradation pathways in the absence of signaling of the Hedgehog and Wingless pathways, said authors suggest that, in man, the genes coding for the homologs of Slimb could be involved in the  
35 proteolytic degradation of  $\beta$ -catenin, a protein which acquires oncogenic properties

when it is not degraded (POLAKIS P., *Biochim. Biophys. Acta*, 1332, F127-47, 1997).

However, despite the fact that conservation of the Wingless and Hedgehog pathways in vertebrates is important, it is not certain that the functions of the homologous proteins will be totally conserved. Moreover, there are numerous examples which show that there are always significant differences between species.

Also, solely on the basis of genetic studies, Jiang et al. established the involvement of Slimb in the control of the Wingless and Hedgehog pathways in *drosophila*. Proof that this control is dependent on a direct interaction between Slimb and Armadillo, for example, has neither been sought nor found.

The protein according to the invention, called h- $\beta$ TrCP, is capable of interacting with virus proteins or cell proteins which can act as mediators or be degraded by proteasome. In particular, the h- $\beta$ TrCP protein is capable of interacting notably with the Vpu protein of HIV-1 virus and with the cell proteins I $\kappa$ B and  $\beta$ -catenin.

It is particularly useful for screening therapeutic agents such as, in particular, antitumoral, antiviral, anti-inflammatory and anti-Alzheimer agents.

The Vpu protein is a small membrane protein of 81 amino acids which is expressed by the majority of isolates of HIV-1 virus but not by those of the considerably less pathogenic HIV-2 virus or by those of SIV simian virus (COHEN et al., *Nature*, 334, 532-534, 1988, and STREBEL et al., *Science*, 2, 1221-1223, 1988).

One of the functions of the Vpu protein is its capacity to induce degradation of the CD4 protein, a cell receptor of HIV-1 virus, so it participates in reducing the expression of the CD4 receptor on the cell surface (Willey et al., *J. Virol.*, 68, 1207-1212, 1994).

It is also known that the two phosphorylation serines of the Vpu protein, located in positions 52 and 56, are essential for the degradation of CD4 induced by Vpu (MARGOTTIN et al., *Virology*, 223, 381-386, 1996). Moreover, during the process of infection by HIV-1 in the absence of the Vpu protein, the Gp160 envelope precursor and the newly synthesized CD4 protein combine in the endoplasmic reticulum to block the maturation of the Gp160 protein (BOUR et al., *J. Virol.*, 65, 6387-6396, 1991). Degradation of the CD4 receptor mediated by the Vpu protein is essential for releasing the viral envelope protein which is held in the endoplasmic reticulum by being bound to CD4 through interaction with the Gp120

subunit, and for allowing the normal maturation of the envelope into the plasmic membrane and subsequently its integration into the virus particles, rendering them infectious. Recent studies have demonstrated the fact that degradation of the CD4 receptor mediated by the Vpu protein is sensitive to specific proteasome inhibitors and is dependent on the presence of an "intact ubiquitinylation machinery" (FUJITA et al., J. Gen. Virol., 78, 619-625, 1997).

Thus the Vpu protein participates in absolutely critical functions for assuring the production of large numbers of infectious virus particles, since it acts not only on the products of the *gag* gene, i.e. on the structural proteins, to increase the release of the virus particles, but also on the products of the *env* gene to allow the maturation of the envelope protein following degradation of the CD4 receptor. In 1996, MARGOTTIN et al. (*supra*) showed that the interaction between Vpu and CD4 took place via their cytoplasmic domain and that this interaction was not sufficient to trigger degradation of the CD4 receptor.

The Skp1p protein is a cell protein involved in the targeting of proteins towards proteasome degradation pathways, which depends on the ubiquitinylation of the proteins (PICKART C.M., The FASEB Journal, 11, 1055-1066, 1997).

BAI et al. (Cell, 86, 263-274, 1996) showed that the Skp1p protein was necessary for ubiquitin-mediated proteolysis and that this degradation took place due to the interaction of Skp1p with proteins containing a unit called F-box.

The Skp1p protein is an essential factor in the targeting of cell cycle regulatory proteins by proteasome. Targeting of the degradation of these regulators is particularly necessary when the cell cycle enters the S phase of DNA synthesis (PAGANO M., The FASEB Journal, 11, 1068-1075, 1997). Recent studies showed that the Skp1p protein and F-box proteins are the essential elements of high-molecular complexes called SCF (Skp1p-Cullin-F-box-protein complexes). These SCF complexes play the role of enzyme E3; through their ubiquitin-ligase activity, they allow the last step of the ubiquitinylation of substrate proteins, which are thus targeted towards degradation by proteasome (HOYT A., Cell, 91, 149-151, 1997). It is further pointed out that no Skp1p homolog has yet been identified in *Drosophila*.

The I $\kappa$ B protein, which exists in different forms ( $\alpha$ ,  $\beta$ ,  $\epsilon$ ), is the major inhibitor of the NF $\kappa$ B transcription factor, keeping it in the form of an inactive complex in the cytoplasm (Beg A. et al., Genes and Dev., 7, 2064-2070, 1993). After stimulation of the cells by factors such as interleukin-1 (IL1) and tumor

necrosis factor (TNF), the I $\kappa$ B protein is phosphorylated on serine residues S32 and S36. This phosphorylation leads very rapidly to the ubiquitinylation of the protein and to the targeting thereof towards degradation by proteasome. The active NF $\kappa$ B factor, for example in the form of two subunits P50 and P65, is then released and imported into the nucleus, where it will be able to activate a very large number of genes and cause inflammatory phenomena in particular.

The  $\beta$ -catenin protein is a cell protein controlling the essential signal transduction pathways such as the Wingless pathways, which are very highly conserved in all vertebrates (MILLER et al., *Genes and Dev.*, 10, 2527-2539, 1996, and POLAKIS P., *Biochim. Biophys. Acta*, 1332, F 127-47, 1997).  $\beta$ -Catenin accumulates in cancerous cells, either as a result of mutations which prevent phosphorylation on serine residues 33 and 37 (mutated  $\beta$ -catenin proteins), or as a result of mutations of its cofactor, the APC protein, which is necessary for its degradation.

The accumulation of  $\beta$ -catenin due to its non-degradation leads to its importation into the nucleus and to the activation of genes controlled by TCF-LEF promoters, causing cell proliferation and transformation phenomena.

It was recently shown that mutations of presenilin-1 in patients suffering from Alzheimer's disease caused a destabilization and enhanced degradation of  $\beta$ -catenin (ZHANG et al., *Nature*, 395, 698-702, 1998). These authors showed that non-mutated presenilin-1 binds to  $\beta$ -catenin and thereby contributes to its stability. In Alzheimer's disease, the mutated presenilin is no longer capable of binding to  $\beta$ -catenin, so the latter is degraded more rapidly. The level of  $\beta$ -catenin is considerably reduced in the neuronal cells of patients suffering from Alzheimer's disease. The loss of  $\beta$ -catenin causes an enhanced apoptosis of the neuronal cells, which would account for the neuronal loss observed in this pathological condition.

It is easy to see that there is an urgent need for means of modulating, namely activating or inhibiting, the targeting of proteins towards proteasome.

A novel human protein involved in the targeting of proteins towards proteasome degradation pathways has now been found which makes it possible to screen modulators of the targeting of proteins towards proteasome.

The present invention therefore relates to a novel human protein, called h- $\beta$ TrCP, which has SEQ ID No. 2 and which is involved in the targeting of proteins towards proteasome degradation pathways.

The h- $\beta$ TrCP protein possesses 569 amino acids and comprises one F-box

and seven WD units having the following positions in the sequence SEQ ID No. 2:

- F-box: amino acids 147-191,
- first WD unit: amino acids 259-292,
- second WD unit: amino acids 304-332,
- 5 - third WD unit: amino acids 343-372,
- fourth WD unit: amino acids 387-415,
- fifth WD unit: amino acids 427-455,
- sixth WD unit: amino acids 467-492,
- seventh WD unit: amino acids 516-544.

10 Because of the homology of this novel protein with the  $\beta$ TrCP of Xenope, a protein containing  $\beta$ -transducin units and known as "beta transducin repeats containing protein", the protein of the invention is called h- $\beta$ TrCP (human  $\beta$ TrCP).

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15 ~~Via its WD units, the h- $\beta$ TrCP protein of the invention is capable of interacting with proteins degradable by proteasome, particularly with virus proteins and cell proteins which possess the phosphorylation unit comprising the amino acids Asp-Ser-Gly-Xaa-Xaa-Ser, in which Xaa is any natural amino acid and in which the serine residues are phosphorylated.~~

The phosphorylation of this unit Asp-Ser-Gly-Xaa-Xaa-Ser is essential to the ubiquitinylation and subsequent degradation of proteins possessing this type of unit. The h- $\beta$ TrCP protein is only capable of interacting with proteins containing this unit when the two serine residues are phosphorylated, and it cannot interact with proteins containing a phosphorylation unit in which the serine residues are mutated to non-phosphorylatable amino acids. By interacting with the phosphorylated proteins on this unit, the h- $\beta$ TrCP protein controls their  
20 ~~ubiquitinylation and their screening towards degradation by proteasome.~~  
*a* 25 ~~ubiquitinylation and their screening towards degradation by proteasome.~~ <sup>targeting</sup>

The virus protein Vpu and the cell proteins I $\kappa$ B and  $\beta$ -catenin may be mentioned in particular among these proteins.

It has also been found that the h- $\beta$ TrCP protein interacts via its F-box with the Skp1p protein, so it forms part of a novel SCF complex, SCF-h- $\beta$ TrCP, which  
30 selects certain cell or virus proteins for degradation by proteasome.

Through its activity of targeting towards proteasome degradation pathways, the h- $\beta$ TrCP protein according to the invention acts as cell mediator of the Vpu protein in cells infected with HIV-1 virus.

Without wishing to exclude other theories, it is thought that, in cells  
35 infected with HIV-1 virus, the virus uses, via the Vpu protein, the SCF complex (of

which the  $\beta$ TrCP protein forms part) to induce degradation of the CD4 receptor, which will favor the replication of the virus and the release of the infectious virions.

5 The invention further relates to the peptide fragments of the h- $\beta$ TrCP protein which result from the addition, deletion and/or replacement of one or more amino acids, said peptide fragments having conserved the activity of interacting with proteins degradable by proteasome, particularly with the Vpu protein of HIV-1 virus, with the cell protein I $\kappa$ B or the cell protein  $\beta$ -catenin and/or with the Skp1p protein.

10 The invention relates in particular to the peptide fragments which comprise at least one of the following amino acid sequences of h- $\beta$ TrCP:

251-569,

292-569,

292-396,

15 292-545 and

1-291.

Very particularly preferred peptide fragments are those which are partially or totally devoid of the F-box or those which are partially or totally devoid of the WD units.

20 One particularly preferred peptide fragment is the mutant with residues 32-179 deleted, which is hereafter called  $\beta$ TrCP $\Delta$ F.

The present invention further relates to the nucleic acid sequences, namely the genomic DNA sequences and the cDNA or mRNA sequences, which comprise or consist of a concatenation of nucleotides coding for the h- $\beta$ TrCP protein or for  
25 any one of its peptide fragments as defined above.

The invention relates notably to those nucleic acid sequences coding for the h- $\beta$ TrCP protein and its peptide fragments described above which are represented by:

- 30 a) the cDNA sequence SEQ ID No. 1 coding for said h- $\beta$ TrCP protein and the cDNA sequences of the nucleic acid fragments coding for said peptide fragments;
- b) the DNA sequences which hybridize with the above sequences under strict conditions;
- 35 c) the DNA sequences which, due to the degeneracy of the genetic code, result from the sequences a) and b) above and code for the h- $\beta$ TrCP protein or its

fragments; and

d) the corresponding mRNA and DNA sequences.

The proteins and peptide fragments according to the invention can be obtained by the genetic engineering technique comprising the following steps:

- 5 - culture of a microorganism or eukaryotic cells which have been transformed with the aid of a nucleic acid sequence according to the invention; and
- recovery of the protein or the peptide fragment produced by said microorganism or said eukaryotic cells.

This technique is well known to those skilled in the art. Further details on  
10 this subject may be obtained by reference to the following work: Recombinant DNA Technology I, Editors Ales Prokop, Raskesh K. Bajpai; Annals of the New York Academy of Sciences, volume 646, 1991.

They can also be prepared by the conventional peptide syntheses well known to those skilled in the art.

15 The nucleic acids according to the invention can be prepared by chemical synthesis and genetic engineering using the techniques well known to those skilled in the art, as described e.g. by SAMBROOK et al. (*supra*).

For example, the cDNA sequences according to the invention can be synthesized by amplifying the mRNAs of human cells by the PCR (Polymerase  
20 Chain Reaction) method, as described e.g. by GOBLET et al. (Nucleic Acid Research, 17, 2144, 1989), using, as primers, synthetic oligonucleotides defined from the DNA sequence SEQ ID No. 1.

The amplified nucleic acid fragment can then be cloned by the techniques described by AUSUBEL et al. (Current Protocols in Molecular Biology, chapter 3,  
25 *supra*).

The invention further relates to transgenic animals which express a transgene for the h- $\beta$ TrCP protein of the invention, or transgenic animals in which the  $\beta$ TrCP gene has been invalidated.

These transgenic animals or animals in which the h- $\beta$ TrCP protein gene has  
30 been invalidated may be used as models for the *in vivo* study of perturbation of the cell cycle and proliferation by the absence or overexpression of the gene for the h- $\beta$ TrCP protein or for truncated or mutated forms of this protein, the Skp1p protein, the Vpu protein, the I $\kappa$ B protein or the  $\beta$ -catenin protein.

These transgenic animals are obtained by techniques well known to those  
35 skilled in the art, such as those described in Manipulating the mouse embryo; a

laboratory manual. HOGAN B., BEDDINGTON R., COSTANTINI F. & LACY E., Cold Spring Harbor laboratory press, second edition, 1994.

The preferred animals are mammals such as mice or rats.

5 The invention further relates to the prokaryotic microorganisms and eukaryotic cells transformed with the aid of an expression vector containing a DNA sequence according to the invention. This expression vector, which can be e.g. in the form of a plasmid, must contain, in addition to the DNA sequence of the invention, the means necessary for its expression, such as, in particular, a promoter, a transcription terminator, an origin of replication and, preferably, a selection  
10 marker. The transformation of microorganisms and eukaryotic cells is a technique well known to those skilled in the art, who will easily be able to determine, as a function of the microorganism to be transformed, the means necessary for the expression of the DNA sequence according to the invention.

The preferred microorganism for the purposes of the invention is *E. coli*,  
15 while the yeast used is preferably *Saccharomyces cerevisiae*.

COS, CHO, SF9, Jurkat and other cells, all of which are listed in the ATCC, may be mentioned in particular as examples of eukaryotic cells which are suitable for the purposes of the invention.

20 The invention further relates to the eukaryotic cells cotransformed with expression vectors containing on the one hand the DNA sequence coding for the Vpu protein, for the Skp1p protein, for the I $\kappa$ B protein or for the mutated  $\beta$ -catenin proteins, and on the other hand a sequence coding for the h- $\beta$ TrCP protein, said expression vectors also containing means useful for their expression, including in the yeast two-hybrid system.

25 The present invention therefore further relates to the anti-HIV-1 antiviral agents consisting of the peptide fragments of the h- $\beta$ TrCP protein of the invention which have conserved the properties of interaction of the h- $\beta$ TrCP protein either with the Vpu protein or with the Skp1p protein. These peptide fragments are devoid of the F-box or the WD units, so they are no longer able to interact with the  
30 Skp1p protein or, respectively, the Vpu protein.

Other antiviral agents, antitumoral agents or anti-inflammatory agents which may be mentioned are antibodies directed against the h- $\beta$ TrCP protein of the invention and its peptide fragments, said antibodies being a further subject of the invention.

35 These antibodies can be monoclonal antibodies obtained by the well-known



method of KOHLER and MILSTEIN (Nature, 256, 495-497, 1975) or polyclonal antibodies obtained by the conventional methods of animal immunization (Antibodies, a laboratory manual. E. Harlow & D. Lane. Cold Spring Harbor laboratory press, 1988).

5 Finally, antiviral agents, antitumoral agents or anti-inflammatory agents which may be mentioned are antisense oligonucleotides which block the transcription or translation of the h- $\beta$ TrCP protein of the invention and which hybridize with a nucleic acid sequence as defined above, said oligonucleotides also forming a further subject of the present invention.

10 These antisense oligonucleotides are prepared by techniques well known to those skilled in the art, such as those described by AUSUBEL et al. (Current Protocols in Molecular Biology, Green Publishing Associates and Wiley-Interscience, New York, 1989, published up to 1997).

15 The peptide fragments of h- $\beta$ TrCP which possess the F-box or which have conserved both the WD units and the F-box can be used as antitumoral or anti-inflammatory agents.

20 The peptide fragments of h- $\beta$ TrCP which are devoid of the F-box can be used in gene therapy for the treatment of osteoarticular inflammatory diseases or acute inflammatory syndromes which are accompanied by NF $\kappa$ B activation induced by the massive release of TNF $\alpha$  during these processes.

25 As illustrated in Figure 7, the expression of h- $\beta$ TrCP $\Delta$ F is capable of massively inhibiting, by a factor of about 20, the transcription activation induced by TNF $\alpha$ . Therefore, h- $\beta$ TrCP $\Delta$ F could act as a potent anti-inflammatory agent in any pathological condition associated with an intense inflammatory reaction due to a release of TNF $\alpha$ . For example, several attempts are currently being made to apply gene therapy to rheumatoid polyarthritis by injecting recombinant viruses into the damaged joints. Vectors expressing h- $\beta$ TrCP $\Delta$ F can be used in these gene therapy experiments on inflammatory syndromes. These vectors may be of several types (retroviruses, adenoviruses; ANDERSON F., Nature, 392, 25-30, 1998). The expression of h- $\beta$ TrCP $\Delta$ F may be monitored by its effects on the inhibition of NF $\kappa$ B activation by TNF.

30 The present invention further relates to the use of the h- $\beta$ TrCP protein, or the nucleic acid sequences coding for this protein or for its peptide fragments, for the screening of therapeutic agents which are capable of modulating the interaction of the h- $\beta$ TrCP protein with proteins degradable by proteasome, and particularly

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for the screening of:

- anti-HIV-1 antiviral agents capable of inhibiting the interaction between the h- $\beta$ TrCP protein and the Vpu protein and/or inhibiting the interaction between the h- $\beta$ TrCP protein and the Skp1p protein;
- 5 • antitumoral agents capable of perturbing the regulation of the cell cycle or the protein degradation processes in tumoral human cells by modulating (inhibiting or activating) the interaction between the h- $\beta$ TrCP protein and the Skp1p protein, and by reactivating the interaction between the h- $\beta$ TrCP protein and the mutated  $\beta$ -catenin proteins in tumoral cells, or between the  $\beta$ TrCP protein and the normal  $\beta$ -catenin protein in tumoral cells devoid of the APC protein;
- 10 • anti-inflammatory agents capable of perturbing the activation of the NF $\kappa$ B transcription factor by inhibiting the interaction between the h- $\beta$ TrCP protein and the I $\kappa$ B protein; and
- 15 • anti-Alzheimer agents capable of reducing the degree of degradation of  $\beta$ -catenin in neuronal cells by inhibiting the interaction between the h- $\beta$ TrCP protein and the  $\beta$ -catenin protein.

In fact, by perturbing the Vpu/h- $\beta$ TrCP and/or Skp1p/h- $\beta$ TrCP interactions, it is possible:

- 20 - either to inhibit the replication and production of HIV-1 virus by infected cells;
- or to inhibit the entry of the cell cycle into the S phase and to have an antiproliferative effect.

By perturbing the I $\kappa$ B/h- $\beta$ TrCP and/or Skp1p/h- $\beta$ TrCP interactions, it is possible to inhibit the degradation of the I $\kappa$ B protein by proteasome and hence to  
25 inhibit the activation of the NF $\kappa$ B transcription factor.

Finally, by activating the mutated  $\beta$ -catenin/h- $\beta$ TrCP interaction, it is possible to activate the degradation of the  $\beta$ -catenin which has accumulated in tumoral cells. By inhibiting the  $\beta$ -catenin/h- $\beta$ TrCP interaction in patients suffering from Alzheimer's disease, it is possible to reduce the apoptosis of neuronal cells.  
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#### Screening of modulators of the h- $\beta$ TrCP/protein interaction

The antiviral agents can be selected either from random peptide banks on the surface of phages (SCOTT J. et al., Science, 249, 386-390, 1990) or by using random synthetic oligonucleotides according to the technique of the SELEX type  
35 (TUERK and GOLD, Science, 249, 505-510, 1990). This technique makes it

possible to isolate, from a very large pool of oligonucleotides, those which have a high affinity for the protein of interest, namely the h- $\beta$ TrCP protein in the present case. They are called aptamers. From these aptamers it will be possible, using the screening method below, to select those which inhibit both the Vpu/h- $\beta$ TrCP and Skp1p/h- $\beta$ TrCP interactions.

The screening method defined above can be carried out e.g. by using the yeast two-hybrid system in which yeast cells co-expressing the h- $\beta$ TrCP protein according to the invention and one of the proteins Vpu, I $\kappa$ B,  $\beta$ -catenin or Skp1p are cultivated on appropriate selective media in the presence of the test substance; the selective media are the media commonly used in this field and hence are well known to those skilled in the art.

The yeast two-hybrid system is described by FIELDS and SONG in *Nature*, 340, 245-246, 1989, and in patent US 5 667 973. This two-hybrid system is based on detection of the protein-protein interactions by activation of the His or LacZ reporter gene under the control of Gal4 transcription activation domains in the yeast.

In this two-hybrid system, a yeast is cotransformed with a two-hybrid vector containing the cDNA of one of the proteins and a vector containing the cDNA of the other protein, each of said vectors containing either a DNA binding domain or a transcription activation domain. The two proteins are then expressed by the yeast in an appropriate culture medium, for example a histidine-free culture medium. The interaction between the two hybrid proteins allows on the one hand activation of the His3 gene and growth of the yeasts on a histidine-free medium, as well as activation of the LacZ gene, which is disclosed by a color reaction specific for  $\beta$ -galactosidase. It is therefore possible to verify the interaction when the yeasts grow on a histidine-free medium and when a color reaction is observed.

A further possibility is to use the halo test as described by Valtz & Peter (*Meth. Enzymol.*, 283, 350-365, 1997) to detect whether there is any interaction.

It is also possible to use variants of the two-hybrid system, such as the three-hybrid system described by TIRODE et al. (*J. Biol. Chem.*, 272, 22995-22999, 1997) or by COLAS et al. (*Nature*, 380, 548-550, 1996), in which a peptide inhibiting the interaction can be expressed as a third partner to inhibit the interaction of the other two. A random peptide bank can also be used in this way.

A further possibility is to use the reverse-hybrid system described by VIDAL et al. (*Proc. Natl. Acad. Sci.*, 93, 10315-10320), in which selection is

carried out against an interaction and not for an interaction. In this system, as in the conventional two-hybrid system, it is possible to screen banks of small chemical molecules, including those derived from chemical synthesis, in order to bring yeasts cotransformed with two-hybrid or reverse-hybrid vectors carrying fusions with the Vpu protein, the I $\kappa$ B protein,  $\beta$ -catenin, the h- $\beta$ TrCP protein or the Skp1p protein into contact with these small molecules in the search for an inhibitor of the Vpu/h- $\beta$ TrCP, Skp1p/h- $\beta$ TrCP,  $\beta$ -catenin/h- $\beta$ TrCP or I $\kappa$ B/h- $\beta$ TrCP interactions.

The screening assays for interaction inhibitors may also be carried out using the conjugative two-hybrid system (FROMONT-RACINE et al., Nature Genetics, 16, 277-282, 1997), the membrane two-hybrid system (BRODER Y.C. et al., Curr. Biol., 8, 1121-1124, 1998) and optionally, if phosphorylations can take place in the bacteria, the bacterial two-hybrid system (KARIMOVA et al., Proc. Natl. Acad. Sci., 95, 5752-5756, 1998).

This screening can also be effected *in vitro* by using one of the proteins Vpu, I $\kappa$ B,  $\beta$ -catenin or Skp1p and the h- $\beta$ TrCP protein, one of the proteins being immobilized on an appropriate support and the other being labeled by any means used in the methods of detecting biological substances, it being possible for this labeling means to be e.g. a radioactive isotope, a luminescent agent, biotin or a specific antibody.

One of the proteins will preferably be immobilized in the form of a fusion protein with glutathione S-transferase (GST) on agarose-glutathione beads or in microtiter plates, the GST serving as an agent for coupling said protein with the beads or with the wells of the plates.

This can be done particularly using the scintillation proximity assay (SPA) described by BOSWORTH et al. (Nature, 341, 167-168, 1989) and marketed by Amersham. This assay consists in labeling one of the proteins with a radioactive element, for example tritium, and immobilizing the other protein on magnetic beads or agarose-glutathione beads. The inhibitory effect of the test substances on interactions involving the h- $\beta$ TrCP protein can easily be detected, without separation of the bound or free radioactive species, according to the protocols described by BOSWORTH et al. (*supra*).

Another possible technique is that of surface plasmon resonances described by KARLSSON et al. (J. Immunol. Methods, 145, 229-233, 1991), using Biacore, marketed by Pharmacia, to isolate the inhibitors of interactions involving the h-

$\beta$ TrCP protein according to the invention.

The inhibitory activity of the antiviral agents selected in this way may be verified by assays on CD<sub>4</sub><sup>+</sup> T cells or on chimpanzees infected with HIV-1 virus or SIV Cpz.

5       The antitumoral agents and anti-inflammatory agents - ligands of the h- $\beta$ TrCP protein of the invention - can also be isolated by the two-hybrid techniques or related techniques or by interaction *in vitro* with combinatorial banks of peptides or other chemical products, as described above.

10       The specificity of the antiviral, antitumoral or anti-inflammatory agents selected by the two-hybrid assay can then be determined by the culture of mammalian cells, for example human cells transfected with the  $\beta$ TrCP protein or a fragment thereof, in the presence of a reporter gene specific for the protein involved in the pathological condition which it is desired to treat.

15       Thus, for the I $\kappa$ B protein, it will be possible to use human cells originating from the cell lines Hela, 293, 293T, etc. and the reporter gene dependent on NF $\kappa$ B sites (3Enh- $\kappa$ B-ConA Luc), which controls the expression of luciferase.

20       In non-stimulated human cells, the human  $\beta$ TrCP protein is transitorily expressed from a eukaryotic expression vector such as pCDNA3 (Invitrogen), or any other eukaryotic expression vector, which has inserted the DNA coding for the  $\beta$ TrCP protein under the control of a strong promoter of the cytomegalovirus, CMV, or the like. An amount of the order of 3  $\mu$ g of this vector permitting the expression of the  $\beta$ TrCP protein will be cotransfected by one of the common transfection techniques (calcium phosphate, lipofectamine (Life Technologies), electroporation (Ausubel and Sambrook, cf. below) etc.) with 1  $\mu$ g of a reporter vector dependent on NF $\kappa$ B sites (3Enh- $\kappa$ B-ConA luc) or independent of NF $\kappa$ B sites (RSV Luc or ConA Luc) which control the expression of the luciferase reporter gene. Molecules capable of inhibiting the h- $\beta$ TrCP/I $\kappa$ B interaction will inhibit the increase in the expression of luciferase in this assay. These inhibitors will be added to the culture medium for at least 6 hours, 24, 36 or 48 hours after transfection. The specificity of these inhibitors may be checked by verifying that they have no effect on RSV Luc or ConA Luc. Another possible alternative will be to use the dual luciferase system from Promega, in which two different reporter vectors can be assayed at the same time.

35       According to one experimental protocol similar to that described above, but with stimulated cells, it will be possible to verify that the inhibition induced by the

expression of the h- $\beta$ TrCP $\Delta$ F fragment on the TNF-dependent transcription activation has been nullified.

Thus, in this second assay, the human cells are cotransfected with 1  $\mu$ g of reporter vector, i.e. either 3Enh- $\kappa$ B-ConA Luc, ConA Luc or RSV Luc, and with 3  $\mu$ g of pCDNA3 expressing the h- $\beta$ TrCP $\Delta$ F peptide fragment, which is a mutant of  $\beta$ TrCP with its F-box deleted. 24 to 48 h after transfection, the cells are treated for 6 h with TNF or okadaic acid (OKA), which are potent NF $\kappa$ B activators (BAUERLE et al., Cell, 1996, 87, 13-20). The h- $\beta$ TrCP $\Delta$ F mutant has a massive inhibitory effect on the expression of the luciferase reporter compared with a control plasmid transfected under the same conditions. This effect is due to the inhibition of I $\kappa$ B degradation induced by the binding of the h- $\beta$ TrCP $\Delta$ F mutant in place of the endogenous wild-type h- $\beta$ TrCP protein. Therefore an inhibitor of the h- $\beta$ TrCP/I $\kappa$ B interaction will also inhibit the h- $\beta$ TrCP $\Delta$ F/I $\kappa$ B interaction and hence will reverse the inhibitory effect of the h- $\beta$ TrCP $\Delta$ F fragment. The potential inhibitors are added to the medium under the same conditions as those indicated above. From the cells stimulated with TNF or OKA, those inhibitors are chosen which induce an increase in the expression of the reporter gene.

After the selection of inhibitors in the previous two assays, a third assay can be carried out to verify that they are capable of inhibiting the activation of NF $\kappa$ B induced by stimulation of the cells with TNF or OKA.

The cells transfected only with 1  $\mu$ g of reporter vector (3Enh- $\kappa$ B-ConA Luc) and stimulated for 6 h with TNF or OKA are treated with the potential inhibitors. To be specific, these inhibitors must have an effect only on the I $\kappa$ B-dependent reporter vectors and not on the other reporter vectors (ConA or RSV).

In the case of  $\beta$ -catenin, it will be possible to use human cells originating from the above lines transformed with mutated  $\beta$ -catenin or the peptide fragment of  $\beta$ TrCP devoid of the F-box, in the presence of vector Top-TK-Luci, which contains a multimer of TCF-LEF sites responding to  $\beta$ -catenin, or Fop-tk Luci, which contains an inactive mutated multimer and no longer responds to  $\beta$ -catenin.

#### Detection of $\beta$ -catenin mutations

Furthermore, as oncogenic mutated  $\beta$ -catenin can easily be distinguished from wild-type  $\beta$ -catenin by the fact that the former, in contrast to the latter, is incapable of binding to  $\beta$ TrCP in the two-hybrid assay,  $\beta$ -catenin mutations can be detected in human tumors by measuring the interaction with  $\beta$ TrCP in the two-

hybrid assay.

This assay is valuable because  $\beta$ -catenin mutations are found in numerous cancers such as colon cancer, melanomas, hepatocarcinomas, etc. The only way of detecting these mutations hitherto was to sequence the  $\beta$ -catenin by carrying out  
 5 RT-PCR on the RNA of the tumors studied. For greater reliability, several double-stranded sequences have to be made in this assay of the prior art. Also, the existence of a mutation does not in itself indicate the oncogenic character of this mutation. It could be a case of polymorphism unconnected with tumorigenicity.

The advantage of the two-hybrid assay with the  $\beta$ TrCP protein is that, in  
 10 times equivalent to those required to obtain a sequence, it is possible to obtain a clear answer regarding the percentage of oncogenic mutated  $\beta$ -catenin sequences detected from the tumoral RNA. Over a large number of colonies, the percentage of oncogenic forms of  $\beta$ -catenin which are incapable of interacting with  $\beta$ TrCP, compared with the wild-type forms which do interact with  $\beta$ TrCP, can be  
 15 determined precisely. The assay can be performed in a time equivalent to that required to obtain a few sequences, and at a reduced cost.

This assay comprises the following steps:

- 1- Preparation of the total RNA from a biopsy of a tumor and of the surrounding healthy tissue, as control, using one of the various RNA preparation techniques or  
 20 kits (AUSUBEL et al., Current Protocols in Molecular Biology).
- 2- Amplification of the  $\beta$ -catenin sequences of the tumor and of the surrounding healthy tissue by carrying out RT-PCR on the RNA samples using a pair of oligonucleotides which permit amplification either of the N-terminal part only (1-130), which contains the most frequently encountered oncogenic mutations  
 25 (RUBINFELD B. et al., Science, 275, 1790-1792, 1997; DE LA COSTE et al., Proc. Natl. Acad. Sci. USA, 95, 8847-8851, 1998), or of the whole of the  $\beta$ -catenin coding sequence.
- 3- Insertion of these amplified fragments, by ligation, into one of the two-hybrid vectors, for example pGAD1318, to give a frame fusion with the Gal4 transcription  
 30 activation domain or the equivalent activation domain for transcription or binding to the DNA coded for by the two-hybrid vector used.
- 4- Transformation of bacteria of various appropriate strains and plating of the whole of the transformant on LB-ampicillin medium.
- 5- Harvesting of all the colonies and plasmid miniprep (AUSUBEL, *supra*).
- 35 6- L40 yeasts or any other appropriate strain of yeast will be cotransformed by the

plasmid containing the  $\beta$ -catenin sequences of the above miniprep with a fusion hybrid containing  $\beta$ TrCP, for example pLexA- $\beta$ TrCP, in which the  $\beta$ TrCP is fused to the LexA DNA binding domain. A two-hybrid assay is performed on all the colonies obtained, for example by plating the cotransformed yeasts on DO-W-L medium and then transferring the colonies to selective medium for detection of the interactions, i.e. DO-W-L-H medium, or in the presence of X-Gal for detection of the interactions by  $\beta$ -galactosidase production (BARTEL P. & FIELDS S., Meth. Enzymol., 254, 241-263, 1995).

This assay requires the following reagents:

- 1- Vector pGAD1318 predigested at the appropriate sites for inserting the amplified fragment obtained by RT-PCR.
- 2- The appropriate oligonucleotides for amplifying the  $\beta$ -catenin sequence and then inserting the amplified  $\beta$ -catenin sequences. The oligonucleotide primers for amplification will be chosen according to the mode of insertion of the amplified fragment and the chosen sites.
- 3- Plasmid pBTM116- $\beta$ TrCP expressing  $\beta$ TrCP fused to the LexA DNA binding domain.
- 4- As control, plasmids coding for fusion hybrids with control proteins, for example pLexRas and pGAD1318Raf.

The gap repair technique (SCHWARTZ H. et al., Mutation detection by a two-hybrid assay, Hum. Mol. Gen., 7, 1029-1032, 1998) may also be applied for this assay in order to insert the sequence of the amplified  $\beta$ -catenin fragment into the two-hybrid vector and transform yeasts directly without proceeding via the step of prior transformation in bacteria.

The invention will now be described in detail with the aid of the following account of experiments.

A large part of the techniques described in these Examples, which are well known to those skilled in the art, is explained in detail in the book by SAMBROOK et al. (*supra*) or in the book by AUSUBEL et al. (*supra*).

The following description will be understood more clearly with the aid of Figures 1 to 12, in which:

- Figure 1A is a photograph of a Petri dish showing the growth of yeast cells cotransformed by plasmids containing Vpu<sub>c</sub> + VBP1, Vpu<sub>c</sub> + h- $\beta$ TrCP, Vpu<sub>c-2/6</sub> + h- $\beta$ TrCP, Vpu<sub>c</sub>, h- $\beta$ TrCP + Vpu<sub>c</sub> and h- $\beta$ TrCP + CD4<sub>c</sub>, on medium in the presence of histidine (His+), on medium in the absence of histidine (His-) and



on medium in the presence of the  $\beta$ -galactosidase substrate X-Gal ( $\beta$ -Gal);

- Figure 1B is a photograph of a gel (Northern blot) showing 3 mRNAs of the h- $\beta$ TrCP protein of the invention;

5 - Figure 1C is a photograph of an immunoblot showing the expression of the h- $\beta$ TrCP protein of the invention;

- Figure 2 shows the sequences of 4 proteins: h- $\beta$ TrCP of the invention,  $\beta$ TrCP1 of *Xenopus*, Met30p of *Saccharomyces cerevisiae* and Scon2p of *Neurospora crassa*;

10 - Figure 3 is a photograph of a 15% SDS-PAGE gel showing the interaction between Vpu<sub>c</sub> and the h- $\beta$ TrCP protein of the invention, produced *in vitro*;

- Figure 4 is a photograph of a Petri dish showing the growth of yeast cells cotransformed by plasmids containing Skp1p + h- $\beta$ TrCP; Skp1p + h- $\beta$ TrCP- $\Delta$ 7W, Skp1p + VBP1 and Skp1p + CD4<sub>c</sub>, on medium in the presence of histidine (His+), on medium in the absence of histidine (His-) and on medium in the presence of the  $\beta$ -galactosidase substrate X-Gal ( $\beta$ -Gal);

15 - Figure 5 is a schematic representation of the degradation of the CD4 receptor induced by the Vpu protein, showing the network of interactions described above;

20 - Figure 6 is a photograph of a Petri dish showing the growth of yeast cells cotransformed by plasmids containing  $\beta$ TrCP + I $\kappa$ B $\alpha$ ,  $\beta$ TrCP + I $\kappa$ B $\alpha$  S32-36AA,  $\beta$ TrCP + Raf, Ras + I $\kappa$ B $\alpha$ ,  $\beta$ TrCP + Vpuc and Ras + Raf, on His+ medium, on His- medium and the expression of  $\beta$ -Gal;

25 - Figure 7 is a graphic representation showing the expression of luciferase (in light units per  $\mu$ g: RLU/ $\mu$ g protein) in cells transfected with the constructs h- $\beta$ TrCP and h- $\beta$ TrCP $\Delta$ AF and the control plasmids and the following reporter vectors: <sup>3</sup>Enh-KB-ConA luc, ConA luc, RSV luc;

30 - Figure 8 is a photograph of an immunoblot showing the detection of the phosphorylated or non-phosphorylated I $\kappa$ B protein and the h- $\beta$ TrCP protein or the h- $\beta$ TrCP $\Delta$ AF fragment, in the presence of anti-I $\kappa$ B $\alpha$ , anti-I $\kappa$ B $\alpha$ -S32<sup>®</sup> and anti-Myc antibodies;

- Figure 9 is a photograph of an immunoblot showing the detection of the phosphorylated or non-phosphorylated I $\kappa$ B protein with the h- $\beta$ TrCP protein or the h- $\beta$ TrCP $\Delta$ AF fragment, in the presence of anti-I $\kappa$ B $\alpha$ -S32<sup>®</sup> and anti-I $\kappa$ B $\alpha$  antibodies;

35 - Figure 10 is a photograph of a Petri dish showing the growth of yeast cells cotransformed by plasmids containing  $\beta$ TrCP +  $\beta$ Cat<sub>1-130</sub>,  $\beta$ TrCP +

$\beta$ Cat<sub>1→130</sub> S33-37AA,  $\beta$ TrCP2 +  $\beta$ Cat<sub>1→130</sub>,  $\beta$ TrCP2 +  $\beta$ Cat<sub>1→130</sub> S33-37AA and  $\beta$ TrCP +  $\beta$ Cat, on His+ medium, on His- medium and the expression of  $\beta$ -Gal;

- Figure 11 is a graphic representation showing the expression of luciferase (RLU/ $\mu$ g protein) in cells transfected with plasmid pcDNA3 and plasmids containing  $\beta$ Cat $\Delta$ N,  $\beta$ TrCP,  $\beta$ TrCP $\Delta$ F, KIA 696 ( $\beta$ TrCP2) and KIA 696  $\Delta$ F ( $\beta$ TrCP2 $\Delta$ F);

- Figure 12 is a photograph of an immunoblot showing a study of the stability of the  $\beta$ -catenin protein detected with anti- $\beta$ Cat antibodies under the influence of the expression of the h- $\beta$ TrCP protein or the h- $\beta$ TrCP $\Delta$ F fragment detected by the anti-Myc antibody.

Example 1: Yeast two-hybrid screening / identification of the cDNA sequence of the h- $\beta$ TrCP protein, and the h- $\beta$ TrCP protein

The chosen target was the cytoplasmic domain of the Vpu protein. Amino acid residues 28 to 81 of the Vpu protein from the LAI isolate of HIV-1 were fused to the Gal4 DNA binding domain (Gal4BD). The cDNA library screened was that of Jurkat cells (human T lymphocyte line, ATCC no. TIB 152) and it was fused to the Gal4 activation domain (Gal4AD) in vector pGAD1318 (BENICHO et al., J. Biol. Chem., 269, 30073-30076, 1994).

The 1.3 kb clone which was initially isolated by the two-hybrid system (called VBP1) codes for a partial complementary DNA. This partial cDNA codes for a 319 amino acid fragment corresponding to the C-terminal domain of the h- $\beta$ TrCP protein. It contains seven repeating units followed by a 24 amino acid C-terminal tail. These repeating units, which are known, are called WD units because their end usually terminates in the sequence Trp-Asp (WD). It will be noted that WD units are involved in protein-protein interactions (NEER et al., Nature, 371, 297-300, 1994).

The clone isolated in this way was characterized by DNA sequencing on an Applied Biosystems automated sequencer known as ABI 373A. The DNA sequencing technique is well known to those skilled in the art and is described especially in the book by SAMBROOK et al. entitled "Molecular Cloning: a Laboratory Manual", published by Cold Spring Harbor Press, NY, 1989.

A cDNA library search showed that this clone is homologous with a sequence coding for the  $\beta$ TrCP protein of Xenope, previously identified by SPEVAK et al. (Mol. Cell. Biol., 13, 4953-4966, 1993).

The complete cDNA (2.1 kb) of the h- $\beta$ TrCP protein, which has SEQ ID No. 1, was obtained by carrying out the polymerase chain reaction (PCR) technique on a plasmid preparation corresponding to the complementary DNA library of Jurkat cells, as defined above, in vector pGAD1318.

5 In addition to the seven WD units identified in the C-terminal fragment, the whole h- $\beta$ TrCP protein according to the invention possesses an N-terminal domain of about 250 amino acids. The N-terminal fragment contains a unit for which a consensus sequence has recently been defined by the term F-box and whose role is supposedly to target proteins towards the protein degradation machinery mediated  
10 by ubiquitin through the interaction of proteins containing this F-box with the Skp1p protein (BAI et al., 1996, *supra*).

Thus, via its WD units, the h- $\beta$ TrCP protein on the one hand is capable of interacting with the Vpu protein and on the other hand possesses an F-box unit which interacts with the Skp1p protein and is therefore capable of targeting  
15 proteins towards proteasome degradation pathways.

The h- $\beta$ TrCP protein possesses 569 amino acids and comprises one F-box and seven WD units having the following positions in the sequence SEQ ID No. 2:

- F-box: amino acids 147-191,
- first WD unit: amino acids 259-292,
- 20 - second WD unit: amino acids 304-332,
- third WD unit: amino acids 343-372,
- fourth WD unit: amino acids 387-415,
- fifth WD unit: amino acids 427-455,
- sixth WD unit: amino acids 467-492,
- 25 - seventh WD unit: amino acids 516-544.

The technique of sequence alignment according to MACAW's program (SCHULER et al., Proteins: structure, function and genetics, 9, 180-190, 1991), a technique well known to those skilled in the art, was used to determine whether the protein isolated in this way had any homology with already known proteins.

30 The results obtained are reported in Figure 2, which shows that the h- $\beta$ TrCP protein has a homology of:

- 88% with the x- $\beta$ TrCP1 protein of *Xenopus*,
- 33% with the Met30p protein of *Saccharomyces cerevisiae*, a transcription inhibitor involved in biosynthesis, and
- 35 • 31% with the Scon2p protein of *Neurospora crassa*.

Figure 2 also shows the location of the F-box and the WD units.

Example 2: Cloning of the cDNA of the h- $\beta$ TrCP protein

*dsca*

5 ~~The cDNA of the h- $\beta$ TrCP protein of SEQ ID No. 1 was amplified by~~  
 carrying out PCR on 2  $\mu$ g of plasmid DNA from the pGAD cDNA library using  
 two amplification turns, the outer pair of primers for the first turn consisting of the  
 sense primer A of SEQ ID No. 3 (in pGAD1318) and the antisense primer B of  
 SEQ ID No. 4 (in VPB1) and the inner pair of primers for the second turn  
 consisting of the sense primer C of SEQ ID No. 5 (in pGAD1318) and the  
 10 ~~antisense primer D of SEQ ID No. 6 (in VPB1).~~

Following this procedure, a 1.4 kb fragment, subcloned in plasmid pGAD-  
 VBP1 in the form of a 5'Spe1-3'BglII fragment, was isolated to reconstitute the  
 pGAD-h- $\beta$ TrCP clone.

15 The sequences coding for VBP1 (amino acid residues 251 to 569 of the  
 h- $\beta$ TrCP protein) or coding for the whole h- $\beta$ TrCP protein were subcloned in  
 vectors pGBT9, pGEX4T2 (Pharmacia) or pCDNA3 (only for the h- $\beta$ TrCP  
 protein) (Invitrogen) using standard procedures.

Example 3: Specific interaction of the Vpu protein with the h- $\beta$ TrCP protein

20 The experimental results which demonstrate the specific interaction of the  
 novel human  $\beta$ TrCP protein with the Vpu protein are illustrated in Figure 1.

3a- Interaction between the Vpu protein and the h- $\beta$ TrCP protein via the  
two-hybrid screen described above

Figure 1A shows the interaction, via the two-hybrid technique, of the C-  
 25 terminal region of the h- $\beta$ TrCP protein (VBP1) originating from the cDNA library  
 of Jurkat cells (line 1), or the whole h- $\beta$ TrCP protein (line 2), fused to the Gal4  
 activation domain, with the Vpu cytoplasmic domain fused to the Gal4 DNA  
 binding domain, or vice-versa (line 5). The interaction is revealed by activation of  
 the two reporter genes His3 and LacZ; the His3 gene permits the growth of yeasts  
 30 in the absence of histidine (-His panel) and the LacZ gene induces the production  
 of  $\beta$ -galactosidase, revealed by the blue coloration in the presence of the substrate  
 X-Gal ( $\beta$ -Gal panel). This interaction is specific since it is not found between the  
 Vpu protein and the vector alone (line 4) or between the h- $\beta$ TrCP protein and  
 another protein such as the cytoplasmic region of CD4 (line 6). The +His panel is  
 35 a control panel showing that all the combinations, including those where there is no

interaction, grow in the presence of histidine.

It should be noted that the h- $\beta$ TrCP protein does not interact with an inactive Vpu protein mutant, Vpuc-2/6 (line 3), a clone mutated on the two serine residues Ser 52 and Ser 56, which are essential for the activity of Vpu (MARGOTTIN et al., 1996, *supra*). This result demonstrates that there is a correlation between the capacity of Vpu to interact with h- $\beta$ TrCP and its activity.

### 3b- Demonstration of the expression of the h- $\beta$ TrCP protein by Northern blot analysis

By Northern blot analysis of the mRNAs of different human cell lines using a 5' probe, it was found that several messenger RNAs (mRNAs) hybridize with a probe corresponding to h- $\beta$ TrCP (Fig. 1B). These mRNAs, of respective sizes 2.4 kb, 3.5 kb and 7 kb, are found in all the human tissues assayed. This multiplicity of mRNAs is reminiscent of the situation described by HUDSON et al. (Dev. Genet., 19, 190-198, 1996) for the mRNAs of the  $\beta$ TrCP of Xenope, for which 3 different mRNAs, with respective sizes similar to those found here for the mRNAs of h- $\beta$ TrCP, were reported.

### 3c- Demonstration of the expression of the h- $\beta$ TrCP protein by Immunoblot analysis

Anti-h- $\beta$ TrCP antipeptide antibodies (Abs) were produced in rabbits by immunization with the synthetic peptide 275-293 corresponding to the first WD unit of the h- $\beta$ TrCP protein. These Abs were purified by the affinity method by adsorption on 30  $\mu$ g of the GST-VBP1 fusion protein, which is expressed in *E. coli* from vector pGEX-VBP1 and immobilized after electroblotting on a nitrocellulose membrane. The purified Abs antibodies were then eluted with the eluent glycine.HCl, pH 3.0, neutralized with 1 M TRIS buffer, pH 8.0, and used for analysis, by the Western blot technique, of the expression of the h- $\beta$ TrCP protein in human Sup T1 cells (T1), in rabbit reticulocytes (RRL) and in canine microsomal membrane lyzates (CMM).

Figure 1C shows the expression of the h- $\beta$ TrCP protein detected in a lyzate of human T cells of the Sup T1 line (line 1) and Promega rabbit reticulocytes (line 3) by the Western blot technique using the previously obtained anti-h- $\beta$ TrCP antibodies directed against the peptide 275-293. On the other hand, no proteins corresponding to h- $\beta$ TrCP could be detected in Promega canine pancreatic microsomal membranes (line 2). The size of the h- $\beta$ TrCP protein detected (60 kD) indicates that the clone of h- $\beta$ TrCP cDNA, which was characterized and is shown

in Figure 2, is capable of coding for the whole h- $\beta$ TrCP protein.

Example 4: Mapping of the sites of interaction between Vpuc and the h- $\beta$ TrCP protein

5 The sites of interaction between the cytoplasmic domain of the Vpu protein (Vpuc) and the h- $\beta$ TrCP protein of the invention were determined as follows:

As regards Vpuc, it was shown that mutation of the serines in positions 52 and 56 (Vpuc-2/6 clone) totally eliminated the interaction between Vpu and h- $\beta$ TrCP.

10 As regards h- $\beta$ TrCP, the results of two-hybrid interaction with the Vpu cytoplasmic domain and the different mutants described below show that all the WD units and the C-terminal tail are required for an optimum interaction, as indicated in the Table below.

The following mutants are used:

15 *a* • ~~VBPI~~ <sup>VBPI</sup>  $\Delta W_1$  (~~VBPI~~ <sup>VBPI</sup> clone in which the first WD domain has been deleted; residues 292 to 569, which correspond to a BglII-XhoI fragment of VBPI);

*a* • ~~VBPI~~ <sup>VBPI</sup>  $\Delta W_{4-7}$  (~~VBPI~~ <sup>VBPI</sup> clone in which WD domains 4 to 7 have been deleted; residues 292 to 396); and

*a* • ~~VBPI~~ <sup>VBPI</sup>  $\Delta C$ -ter (~~VBPI~~ <sup>VBPI</sup> clone in which the C-terminal tail after the 7th WD domain has been deleted; residues 292 to 545)

20 by PCR using respectively the sense primer C, described above, and the following antisense primers E and F in VBPI:

primer E: SEQ ID No. 7

primer F: SEQ ID No. 8

25 The h- $\beta$ TrCP- $\Delta 7W$  mutant (h- $\beta$ TrCP clone in which the seven WD domains have been deleted; residues 1 to 291) was constructed by inserting an SpeI-BglII fragment from the h- $\beta$ TrCP protein into vector pGAD1318, and the  $\beta$ TrCP $\Delta F$  mutant (deleted residues: 32 to 179) was obtained by deleting the AvrII-Asp718 fragment of the h- $\beta$ TrCP protein with conservation of the reading frame.

30 The following method was used to verify that the interaction between the Vpu and h- $\beta$ TrCP proteins could take place *in vitro*: the two proteins were introduced into rabbit reticulocyte lysate (RRL). The Vpu/ $\beta$ TrCP complexes formed *in vitro* were identified by co-immunoprecipitation using anti-h- $\beta$ TrCP antibodies directed against the peptide 553-569, which were prepared by the same  
35 method as that used to obtain the anti-h- $\beta$ TrCP antibodies directed against the

5

10

TABLE

Deletion mutants of h- $\beta$ TrCP		Interaction with Vpuc
h- $\beta$ TrCP:	— <span style="border: 1px solid black; padding: 0 2px;">F</span> — <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">1</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">2</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">3</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">4</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">5</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">6</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">7</span> —	+++
VBP1:	— <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">1</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">2</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">3</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">4</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">5</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">6</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">7</span> —	+++
VBP1- $\Delta$ W1:	<span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">2</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">3</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">4</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">5</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">6</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">7</span> —	-
VBP1- $\Delta$ C-ter:	— <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">1</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">2</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">3</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">4</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">5</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">6</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">7</span> —	+
VBP1- $\Delta$ W4-7:	— <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">1</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">2</span> <span style="border: 1px solid black; border-radius: 50%; padding: 0 2px;">3</span> —	+
h- $\beta$ TrCP- $\Delta$ 7W:	— <span style="border: 1px solid black; padding: 0 2px;">F</span> —	-



Example 5: Interaction between the h- $\beta$ TrCP protein and the Skp1p protein

To demonstrate that the F-box unit was indeed functional and could therefore effectively be used for targeting towards proteasome via the Skp1p protein, a two-hybrid assay was performed between the N-terminal domain of the h- $\beta$ TrCP protein and the Skp1p protein, making it possible to reveal an interaction between the h- $\beta$ TrCP protein and the Skp1p protein.

The human Skp1p protein described by BAI et al. (1996, *supra*) was subcloned into vector pLex10 for analysis of the interaction with the h- $\beta$ TrCP protein in the yeast strain L40 (VOJTEK et al., Cell, 74, 205-214, 1993).

Figure 4 illustrates the results obtained. Line 1 of Figure 4 shows first of all that the h- $\beta$ TrCP protein interacts with the Skp1p protein. Line 2 shows that the N-terminal domain is sufficient to obtain the interaction, whereas line 3 shows that the absence of the N-terminal domain of the h- $\beta$ TrCP protein in VBP1 removes all interaction with the Skp1p protein. These results are important additional arguments in favor of a role of the h- $\beta$ TrCP protein in degradation of the CD4 receptor mediated by the Vpu protein, and also corroborate the results of FUJITA et al. (1997, *supra*) and SCHUBERT et al. (1997, *supra*), showing that degradation of the CD4 receptor induced by the Vpu protein ought to take place in proteasome. It should be noted that the CD4 cytoplasmic domain is incapable of binding directly to the <sup>Skp1p</sup> Skp1 protein (line 4).

Example 6: Model of the network of interactions involved in degradation of the CD4 receptor

Degradation of the CD4 receptor induced by the Vpu protein is effected by the network of interactions a) between the Vpu protein and the CD4 receptor, b) between the Vpu protein and the WD units of the h- $\beta$ TrCP protein, and c) between the F-box of the h- $\beta$ TrCP protein and the Skp1p protein, this last interaction allowing d) the targeting of the Vpu/CD4 complex towards proteasome.

This network of interactions is illustrated schematically in Figure 5.

It is by way of such a network of interactions that degradation of the CD4 receptor by proteasome via the Vpu protein is caused.

Degradation of the CD4 receptor allows the release of the Gp160 envelope protein and hence the release of infectious HIV-1.

One of the means of preventing the development of HIV-1 in the affected patient therefore consists in preventing degradation of the CD4 receptor. One of

the means of preventing this degradation in the light of the above degradation process consists in looking for inhibitors, or anti-HIV antiviral agents, which inhibit the interaction either between the Vpu protein and the h- $\beta$ TrCP protein, or between the h- $\beta$ TrCP protein and the Skp1p protein, by the processes described above.

Example 7: Interaction between the h- $\beta$ TrCP protein and the I $\kappa$ B protein

For this yeast two-hybrid assay, the proteins described below were fused either to the Gal4 transcription activation domain (Gal4AD) or to the LexA DNA binding domain:

- $\beta$ TrCP = human  $\beta$ TrCP protein of the present invention,
- I $\kappa$ B $\alpha$ ,
- I $\kappa$ B $\alpha$  S32-36A = I $\kappa$ B $\alpha$  mutant at serines S32 and S36 so that there is no phosphorylation,
- Ras = control protein,
- Raf = control protein,
- Vpuc = cytoplasmic Vpu protein as described above.

The experimental results which demonstrate the specific interaction of the novel human  $\beta$ TrCP protein with the I $\kappa$ B protein are illustrated in Figure 6.

This two-hybrid assay shows that:

- the two proteins h- $\beta$ TrCP and I $\kappa$ B are capable of interacting,
- the h- $\beta$ TrCP/I $\kappa$ B interaction is specific for the two hybrids since, when one of the two hybrids is replaced by a hybrid with another protein, such as Gal4AD-Raf or LexABD-Ras, there is no longer any interaction, whereas these two control hybrids are capable of interacting, and
- this interaction is removed when serine residues S32 and S36 of the I $\kappa$ B protein are mutated to non-phosphorylatable residues like alanine.

An interaction between the Vpu protein of HIV-1 and the h- $\beta$ TrCP protein was also observed in this assay.

Example 8: I $\kappa$ B/h- $\beta$ TrCP interaction in human cells: modulation of the transcription activation of reporter genes for NF $\kappa$ B activity by expression of the h- $\beta$ TrCP protein or its h- $\beta$ TrCP $\Delta$ F fragment

In non-stimulated cells (NS) of the 293 cell line, the human  $\beta$ TrCP protein or the h- $\beta$ TrCP $\Delta$ F fragment is transitorily expressed from a eukaryotic expression

vector such as pCDNA3 (Invitrogen), following insertion of the cDNA coding for the h- $\beta$ TrCP protein under the control of a strong cytomegalovirus promoter (CMV). An amount of 3  $\mu$ g of this plasmid permitting expression of the h- $\beta$ TrCP protein or the h- $\beta$ TrCP $\Delta$ F fragment is cotransfected by lipofectamine (Life Technologies) with 1  $\mu$ g of a reporter vector dependent on NF $\kappa$ B sites (3Enh- $\kappa$ B-ConA Luc) or independent of NF $\kappa$ B sites (RSV Luc or ConA Luc) which control the expression of the luciferase reporter gene.

The results obtained (Figure 7) show that the h- $\beta$ TrCP $\Delta$ F fragment is capable of acting as a negative transdominant. By competing with the endogenous  $\beta$ TrCP, the h- $\beta$ TrCP $\Delta$ F fragment inhibits the activation of NF $\kappa$ B induced by TNF or okadaic acid (OKA). This activation of NF $\kappa$ B is measured by the activity of a reporter gene under the control of a promoter which has three NF $\kappa$ B binding sites (3Enh- $\kappa$ B-ConA Luc) (Arenzana et al., 1993, J. Virol., 67, 6596-6609). On the other hand, the h- $\beta$ TrCP protein has an activatory effect on the activation of NF $\kappa$ B. The h- $\beta$ TrCP protein or the h- $\beta$ TrCP $\Delta$ F fragment has no effect on the transcription of a reporter gene directed by a promoter which does not contain NF $\kappa$ B sites (RSV Luc) (Invitrogen).

Example 9: Use of specific antibodies for revealing the interaction between the h- $\beta$ TrCP protein and the endogenous I $\kappa$ B protein of 293 or Hela cells, and its consequences on the stability of the I $\kappa$ B protein

The stability of the phosphorylated forms of I $\kappa$ B was analyzed in 293 cells transfected by a control plasmid, by a pcDNA plasmid (Invitrogen) expressing the h- $\beta$ TrCP protein, or by a pcDNA plasmid expressing the h- $\beta$ TrCP $\Delta$ F fragment, the h- $\beta$ TrCP protein and the h- $\beta$ TrCP $\Delta$ F fragment having been fused to the myc epitope at the C-terminal end of this pcDNA vector. After 36 hours, the 293 cells were stimulated with TNF in the presence of 100  $\mu$ g/ml of cycloheximide (protein synthesis inhibitor). The cytoplasmic proteins were separated on denaturing polyacrylamide gel/SDS and then transferred to a nitrocellulose membrane and incubated either with the 10B monoclonal antibody directed against the amino-terminal part of I $\kappa$ B and recognizing all forms of the protein ( $\alpha$ -I $\kappa$ B $\alpha$ ; JAFFRAY et al., Mol. Cell. Biol., 15, 2166-2172, 1995), or with a polyclonal antibody specifically recognizing the phosphorylated forms of I $\kappa$ B ( $\alpha$ -I $\kappa$ B $\alpha$ -S32<sup>®</sup>; 9241S, New England Biolabs), or with an anti-myc monoclonal antibody directed against the myc epitope fused to h- $\beta$ TrCP and h- $\beta$ TrCP $\Delta$ F and showing the expression of

the latters in the transfected cells ( $\alpha$ -Myc; SC40AC, Santa Cruz), by carrying out a Western blot (WB).

The results obtained (Figure 8) show that the expression of the h- $\beta$ TrCP $\Delta$ F mutant is accompanied by inhibition of the degradation of I $\kappa$ B normally induced by TNF. Under the influence of the expression of h- $\beta$ TrCP $\Delta$ F, the phosphorylated forms accumulate, as shown by the reactivity of the  $\alpha$ -I $\kappa$ B $\alpha$ -S32<sup>®</sup> antibodies (right panel).

The h- $\beta$ TrCP protein, on the other hand, activates the degradation of I $\kappa$ B $\alpha$  (middle panel). The bottom panel, relating to the  $\alpha$ -Myc antibody, is a control panel showing the expression of the h- $\beta$ TrCP and h- $\beta$ TrCP $\Delta$ F proteins.

The h- $\beta$ TrCP/I $\kappa$ B interaction was also confirmed by an immunoprecipitation experiment.

To do this, Hela cells were transfected with a control pcDNA plasmid expressing  $\beta$ -galactosidase ( $\beta$ -Gal), the h- $\beta$ TrCP protein ( $\beta$ TrCP) or the h- $\beta$ TrCP $\Delta$ F mutant ( $\beta$ TrCP $\Delta$ F), h- $\beta$ TrCP and h- $\beta$ TrCP $\Delta$ F having been fused to an myc epitope at the C-terminal end. After 36 hours, the Hela cells were stimulated for 15 minutes with TNF in the presence of proteasome inhibitors (z-LLL-H) (PALOMBELLA V. et al., Cell, 78, 773-789, 1994) (z-LLL-H + TNF; + reaction) or left without stimulation (- reaction). The subsequent procedure then consisted either of a direct immunoblot after separation of the proteins in the cell lysate on denaturing gel/SDS and transfer to a nitrocellulose membrane incubated with  $\alpha$ -I $\kappa$ B $\alpha$ -S32<sup>®</sup> antibodies (top panel), or to an immunoprecipitation with  $\alpha$ -Myc antibodies followed by an immunoblot, as indicated above, with the  $\alpha$ -I $\kappa$ B $\alpha$ -S32<sup>®</sup> antibody or the  $\alpha$ -I $\kappa$ B $\alpha$  antibody.

The results are indicated in Figure 9, in which the top panel shows the results of the Western blot only and the bottom two panels show those of the immunoprecipitation/Western blot, and the right panel gives the pattern of migration of the phosphorylated forms induced by treatment with TNF on control Hela cells.

By means of experiments involving the co-immunoprecipitation of the h- $\beta$ TrCP protein or the h- $\beta$ TrCP $\Delta$ F fragment fused to the myc epitope, Figure 9 shows that only the phosphorylated form of I $\kappa$ B $\alpha$ , and not the non-phosphorylated form, is associated with the h- $\beta$ TrCP protein (column 4). This association is disclosed especially through the inhibition of degradation induced by the h- $\beta$ TrCP $\Delta$ F mutant (columns 5 and 6) and the use of proteasome inhibitors (z-LLL-

H).

Example 10: Interaction between the h- $\beta$ TrCP protein and the  $\beta$ -catenin protein

For this two-hybrid assay, the cDNAs coding for the proteins described below were fused either to the Gal4 transcription activation domain (Gal4AD) or to the LexA DNA binding domain (LexABD):

- $\beta$ TrCP = human  $\beta$ TrCP protein of the present invention,
- KIAA 0696 ( $\beta$ TrCP2) = human  $\beta$ TrCP protein isolated by ISHIKAWA et al. (DNA Research, 5, 169-176, 1998),
- $\beta$ Cat<sub>1→130</sub> = normal  $\beta$ -catenin protein (N-terminal domain; 1→130),
- $\beta$ Cat<sub>1→130</sub> S33-37AA = oncogenic  $\beta$ -catenin protein mutated on serine residues S33 and S37 so that there is no phosphorylation,
- $\beta$ Cat = whole normal  $\beta$ -catenin protein.

The experimental results, which demonstrate that there is a specific interaction of the novel human  $\beta$ TrCP protein with the  $\beta$ -catenin protein, are illustrated in Figure 10.

This two-hybrid assay shows that:

- the two proteins h- $\beta$ TrCP and  $\beta$ Cat<sub>1→130</sub> are capable of interacting,
- the h- $\beta$ TrCP/ $\beta$ Cat<sub>1→130</sub> interaction is removed when serine residues S33 and S37 are mutated to non-phosphorylatable residues (oncogenic  $\beta$ -catenin), and
- $\beta$ TrCP2 is not capable of reacting either with non-mutated  $\beta$ -catenin or with mutated  $\beta$ -catenin.

It should be noted that an interaction is also observed between the whole  $\beta$ -catenin protein and the h- $\beta$ TrCP protein.

Example 11: Activation of the transcription of the TCF/LEF reporter gene by the expression of mutated  $\beta$ -catenin or h- $\beta$ TrCP $\Delta$ F in human 293 cells

HEK 293 cells were transfected with reporter vector Top-TK-Luci, which contains a multimer of TCF-LEF sites, or reporter vector Fop-TK-Luci, which contains an inactive control multimer of TCF-LEF sites. These constructs are cotransfected with expression vector pCDNA3 (Invitrogen), either void as control, or expressing an oncogenic  $\beta$ -catenin fragment, namely  $\beta$ -catenin devoid of the N-terminal part,  $\beta$ Cat $\Delta$ N, or expressing the h- $\beta$ TrCP protein or the  $\beta$ TrCP $\Delta$ F fragment. The luciferase activity is measured 24 h after transfection and standardized to a control Renilla luciferase activity obtained by the cotransfection of cells with vector RSV-Renilla (Promega).

The results obtained, which are given in Figure 11, show that the h- $\beta$ TrCP $\Delta$ F fragment induces the activation of a reporter gene controlled by a TCF/LEF promoter, which responds to modifications in  $\beta$ -catenin expression level (Morin P.J. et al., 1997, Science, 275, 1787-1790). This indicates that the degradation of  $\beta$ -catenin is inhibited by expression of the h- $\beta$ TrCP $\Delta$ F mutant. On the other hand, as regards the KIAA 0696 protein,  $\beta$ TrCP2, in the same reporter gene system, the positive effect induced by KIAA 0696  $\Delta$ F ( $\beta$ TrCP2 $\Delta$ F) is much weaker than that obtained with the equivalent  $\beta$ TrCP $\Delta$ F construct.

Taken together, these results therefore demonstrate that it is the h- $\beta$ TrCP protein of the invention, and not the KIAA 0696 protein, which is the mediator of  $\beta$ -catenin degradation.

Example 12: Study of the expression of the h- $\beta$ TrCP protein or the h- $\beta$ TrCP $\Delta$ F fragment on the stability of the endogenous  $\beta$ -catenin of Hela cells

Hela cells were transfected with the amounts of DNA indicated in Figure 12, expressing either the h- $\beta$ TrCP protein or the h- $\beta$ TrCP $\Delta$ F fragment fused to the myc epitope at the C-terminal end in a pcDNA vector (Invitrogen). After 24 hours, the cells were lysed and the cell proteins were separated on denaturing polyacrylamide gel/SDS, transferred to a nitrocellulose membrane and incubated either with an anti- $\beta$ -catenin antibody ( $\alpha$ - $\beta$ Cat), or with an anti-myc antibody for detecting the expression of the h- $\beta$ TrCP protein or the h- $\beta$ TrCP $\Delta$ F fragment ( $\alpha$ -Myc), by carrying out a Western blot (WB).

The results are indicated in Figure 12 and show that the expression of h- $\beta$ TrCP increases the degradation of  $\beta$ -catenin (middle column), whereas the expression of the h- $\beta$ TrCP $\Delta$ F mutant inhibits the degradation of  $\beta$ -catenin and leads to its accumulation in the cells (right column).

It should be noted that column C shows a control of non-transfected Hela cells; the asterisk indicates, by the non-specific labeling of a cell protein in the Hela cell lysate, that approximately the same amount of cell proteins has been deposited in all the lanes.

The results corroborate those shown in the previous Example.